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PATENT APPLICATION

ATTORNEY DOCKET NO. 10991682-1

IN THE
UNITED STATES PATENT AND TRADEMARK OFFICE

Inventor(s): Sorin et al.

Serial No.: 09/488,149 **Examiner:** Wang, George

Filing Date: 01/20/2000 **Group Art Unit:** 2878

Title: SYSTEM AND METHOD FOR OPTICAL HETERODYNE DETECTION OF AN OPTICAL SIGNAL THAT UTILIZES OPTICAL ATTENUATION

ASSISTANT COMMISSIONER FOR PATENTS
PO Box 1450
Alexandria, VA 22313-1450

TRANSMITTAL OF APPEAL BRIEF

Sir:

Transmitted herewith in triplicate is the Appeal Brief in this application with respect to the Notice of Appeal filed on **10/02/2003**.

The fee for filing this Appeal Brief is (37 CFR 1.17(c)) $330.00.

(complete (a) or (b) as applicable)

The proceedings herein are for a patent application and the provisions of 37 CFR 1.136(a) apply.

( ) (a) Applicant petitions for an extension of time under 37 CFR 1.136 (fees: 37 CFR 1.17(a)-(d) for the total number of months checked below:

( )	one month	$110.00
( )	two months	$420.00
( )	three months	$950.00
( )	four months	$1480.00

( ) The extension fee has already been filled in this application.

(X) (b) Applicant believes that no extension of term is required. However, this conditional petition is being made to provide for the possibility that applicant has inadvertently overlooked the need for a petition and fee for extension of time.

Please charge to Deposit Account 50-1078 the sum of **$330.00**. At any time during the pendency of this application, please charge any fees required or credit any overpayment to Deposit Account 50-1078 pursuant to 37 CFR 1.25.

(X) A duplicate copy of this transmittal letter is enclosed.

(X) I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Commissioner for Patents, PO Box 1450, Alexandria, VA 22313-1450.
Date of Deposit: **12/02/2003** or

I hereby certify that this paper is being facsimile transmitted to the Patent and Trademark Office on the date shown below.
( ) Date of Facsimile:

Typed Name: Mark A. Wilson

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Respectfully submitted,

Sorin et al.

By Mark A. Wilson

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Attorney Docket No. 10991682-1 PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

Appellant: Sorin et al. Group Art Unit: 2878
Serial No. 09/488,149 Examiner: Wang, George
Filed: January 20, 2000
For: SYSTEM AND METHOD FOR OPTICAL HETERODYNE DETECTION OF AN OPTICAL SIGNAL THAT UTILIZES OPTICAL ATTENUATION

Assistant Commissioner for Patents
Washington, D.C. 20231

BRIEF ON APPEAL

Sir:

This brief is in furtherance of Applicants' Notice of Appeal filed October 2, 2003, appealing the decision of the Examiner dated August 26, 2003 finally rejecting claims 1 – 20. A copy of the claims appears in the Appendix to this brief. This brief is transmitted in triplicate.

CERTIFICATE OF MAILING UNDER 37 C.F.R. 1.8
I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being deposited with the United States Postal Service on the date shown below with sufficient postage as "U.S. Express Mail" in an envelope addressed to: Assistant Commissioner for Patents, Washington, D.C. 20231

Date: December 2, 2003 Signed: Mark A. Wilson

Express Mail Label No.: ER 264470957US Typed Name: Mark A. Wilson

I. Real Party in Interest

The real party in interest in this appeal is Agilent Technologies, Inc., a Delaware Corporation, having a place of business at 395 Page Mill Road, Palo Alto, California 94303.

II. Related Appeals and Interferencs

There are currently no related appeals or interference proceedings in progress that will directly affect, or be directly affected by, or have a bearing on the Board's decision in the present Appeal.

III. Status of Claims

Claims 1 – 4, 11, 12, 14, and 15 were rejected under 35 U.S.C. 103(a) as being unpatentable over AAPA (Applicant's Admission of Prior Art) and Sorin (U.S. Patent No. 5,365,335) in view of Hasegawa et al. (U.S. Patent No. 4,553,264, hereinafter Hasegawa) and Evans et al. (U.S. Patent No. 4,048,573, hereinafter Evans).

Claims 1 – 20 were originally filed with the application. No claims have been amended, canceled, or added. This Appeal is made with regard to pending claims 1 – 20.

IV. Status of Amendments

There are no pending amendments.

V. Summary of the Invention

The claimed invention involves methods and systems for characterizing an optical signal utilizing optical heterodyne detection. The methods and systems, as recited in independent claims 1, 11, and 14, involve attenuating an input signal, combining the attenuated input signal with a local oscillator signal and detecting the combined optical signal. The input signal is attenuated before being combined with the local oscillator signal in order to improve the signal to noise ratio of the

heterodyne signal that is generated when the combined optical signal is detected. The signal to noise ratio of the heterodyne signal improves with attenuation of the input signal, specifically in the case where the intensity noise from the input signal is the dominant noise source, because the heterodyne signal and the intensity noise of the input signal scale differently with attenuation of the input signal.

A method for monitoring an optical signal utilizing optical heterodyne detection, as recited in claim 1, includes providing an input signal and a local oscillator signal and attenuating the input signal. The attenuated input signal is combined with the local oscillator signal to create a combined optical signal. The combined optical signal is detected and an output signal that is indicative of an optical parameter of the input signal is generated. In an embodiment of the method, the level of attenuation of the input signal is adjusted to maximize the signal to noise ratio of the heterodyne signal.

Another method for monitoring an optical signal utilizing optical heterodyne detection, as recited in claim 11, includes providing an input signal and a local oscillator signal and attenuating the input signal before the input signal and the local oscillator signal are combined. The attenuated input signal is then combined with the local oscillator signal to create a combined optical signal. The combined optical signal includes a heterodyne signal, intensity noise from the input signal, and shot noise. An electrical signal is generated in response to the combined optical signal. An output signal that is indicative of an optical parameter of the input signal is generated from the electrical signal. Additionally, the level of attenuation of the input signal is adjusted to maximize the signal to noise ratio of the heterodyne signal.

An embodiment of an optical heterodyne detection system, as recited in claim 14, includes an attenuator (224), an optical coupler (210), and a receiver (212). The attenuator has an input to receive an input signal (202) and an output for outputting an attenuated input signal. The optical coupler has a first input that is optically connected to the attenuator to receive the attenuated input signal and a second input that receives a local oscillator signal (206). The optical coupler combines the attenuated input signal and the local oscillator signal to create a combined optical signal and outputs the combined optical signal through an output. The optical receiver receives the combined optical signal from the optical coupler and generates an electrical signal that is representative of the combined optical signal.

An embodiment of the optical heterodyne detection system also includes a processor (216) that utilizes the electrical signal from the receiver (212) to generate an output signal that is indicative of an optical parameter of the input signal (202). The processor monitors the heterodyne signal that is a component of the combined optical signal in order to generate the output signal.

In an embodiment of the optical heterodyne detection system, the attenuator (224) is adjustable so that the input signal can be attenuated to different levels. Preferably, the attenuator is adjusted to attenuate the input signal to a level that maximizes the signal to noise ratio of the heterodyne signal. In an embodiment, the signal to noise ratio is maximized when the intensity noise of input signal is approximately equal to the shot noise of the local oscillator signal. A feedback loop (226) may be provided between the processor and the adjustable attenuator so that the attenuator can be adjusted in response to real-time measurements of the signal to noise ratio of the heterodyne signal.

Before utilizing the system to measure an input signal it may be necessary to calibrate the system. The attenuator may be utilized to block transmission of the input signal so that the optical coupler and the receiver can be calibrated.

VI. Issues

Whether claims 1 – 4, 11, 12, 14, and 15 are obvious under 35 U.S.C. 103(a) as being unpatentable over the AAPA and Sorin in view of Hasegawa and Evans.

VII. Grouping of Claims for Each Contested Ground of Rejection

Regarding the rejection under 35 U.S.C. 103(a), claims 1 – 3, 11, 14, and 15 stand or fall together and claims 4 and 12 stand or fall together. Reasons why claims 4 and 12 are believed to be separately patentable are explained in the Argument section.

VIII. Argument

Applicants maintain that the Examiner has failed to make a *prima facie* case of obviousness under 35 U.S.C. 103(a) which requires that three basic criteria must be met, as set forth in M.P.E.P 2142:

> "First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art reference (or references when combined) must teach or suggest all of the claim limitations."

The initial burden is therefore on the Examiner to establish a *prima facie* case of obviousness under 35 U.S.C. 103(a).

Applicants assert that claims 1 – 4, 11, 12, 14, and 15 are not rendered obvious from AAPA and Sorin in view of Hasegawa and Evans because a *prima facie* case of obviousness has not been established. Applicants assert that a *prima facie* case of obviousness has not been established because the Examiner has not presented some suggestion or motivation, either in the references themselves, or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine the reference teachings. In addition, with regard to claims 4 and 12, Applicants assert that even if the prior art references were combined, the combined references fail to teach or suggest all of the claim limitations.

Background on the AAPA, Sorin, Hasewaga, and Evans

Applicants disclose a known optical heterodyne detection system in Fig. 1 of the specification. The optical heterodyne detection system includes an input waveguide (104), a local oscillator waveguide (108), an optical coupler (110), an output waveguide (118), an optical receiver (112), and a signal processor (116).

Sorin discloses a "low-coherence reflectometer for use in measuring backscattering." (Abstract) That is, Sorin discloses a reflectometer that is used to measure the optical properties (specifically, the reflective properties) of a device. The device, whose optical properties are being measured by the reflectometer, is often referred to as the device under test or "DUT".

The reflectometer disclosed by Sorin in Fig. 3 includes a light source (214), a coupler (216), a device under test (12), an attenuator (240), mirrors (224 and 231), a detector (227), and an analyzer (219). The purpose of the attenuator in the reflectometer disclosed by Sorin is to attenuate the reference signal. According to Sorin, the reference signal is attenuated because the power of the reference signal returned via fiber (223), in many cases of interest, is too large in comparison to the signal from the device under test (12) (the backscattered light). (col. 4, lines 39 – 48) As stated in Sorin at col. 5, lines 16 – 18, "according to the present invention, the reference power is decreased by including an attenuator in the reference *and* of the interferometer." (Applicants assume that the word "and" was a translation error and that the word should be read as "end")

Hasegawa discloses a double superheterodyne tuner used for the VHF and/or UHF band (col. 1, lines 5 – 9).

Evans discloses improvements in high fidelity electrical amplifiers to minimize clipping.

Basis of Rejection for Obviousness

The Final action of August 26, 2003 states that the AAPA and Sorin disclose "a device and method of monitoring an optical signal utilizing a heterodyne detection (fig. 3, ref. 200) comprising steps of providing an input signal (fig. 3, ref. 214), a local oscillator signal (fig. 3, ref. 220), combining them (fig. 3, ref. 216), detecting the combined signal (fig. 3, ref. 12) of heterodyne, intensity and shot noise, and generating an output signal that is indicative of an optical parameter of input signal and includes monitoring a heterodyne signal." The Final action goes on to state that the "AAPA and Sorin fail to disclose an attenuator positioned before heterodyne signal combination" (Final action, August 26, 2003, page 3, item 2) but that "Hasegawa discloses a heterodyne tuner with an attenuator positioned immediately after the input (fig. 8, ref. 62)" and that "Evans discloses amplification improvements that include attenuation at the input (fig. 1; abstract)." The Office action concludes that it would have been obvious "to have positioned the attenuator of Sorin immediately after the input port and before the signal combination as suggested by Hasegawa since the noise intensity from the input signal is usually a dominant noise source (fig. 8, ref. 62)." (Office action page 3, item 2) From this statement, Applicants assume that the Examiner is suggesting that it would have been obvious to

change the position of the attenuator (240), as disclosed in Fig. 3 of Sorin, from fiber (223) to fiber (213) such that the attenuator is located between the light source (214) and the coupler (216). The Final action goes on to state:

> "Although the placing the attenuator immediately following the input signal achieves the same functional purpose as placing it after the coupler to provide attenuation feedback, it is clear that placing it at the site of dominant noise generation would render it more advantageous and beneficial because attenuators are well known in the art and are widely used to reduce noise levels. Therefore, maximizing signal to noise ratio at the dominant noise source would have been obvious to do for any optical system (Evans, abstract)."

<u>Evans does not provide the motivation behind the suggested combination</u>

Applicants assert that the Office action does not identify a suggestion or motivation either in the AAPA, Sorin, Hasegawa, Evans or in the knowledge generally available to one of ordinary skill in the art, to combine Hasegawa and Evans with the AAPA and Sorin. Specifically, with regard to Evans, Applicants assert that the Examiner has relied upon false assumptions as the basis for the motivation behind the suggested combination.

In reference to Evans, the Final action states that "Evans discloses amplification improvements that include attenuation at the input (fig. 1, Abstract)." The Final action goes on to state that "[a]ttenuators are well known in the art and are widely used to reduce noise levels", and "[t]herefore, maximizing signal to noise ratio at the dominant noise source would have been obvious to do for any optical system (Evans, abstract)." In the "Response to Arguments" section of the August 26, 2003 Final action, the Examiner states:

> "So Examiner argues that the statement that attenuators are well known in the art and widely used to reduce noise levels is relevant, especially in light of the Evans reference, which is directed toward attenuation at the input. For this reason, it is clear that an attenuator is not only able to reduce noise levels or maximize signal to noise ratio, but able to do so at the input or dominant noise source. This is the motivation behind the suggestive combination that Applicant has misinterpreted."

In response to the above-identified quotations, Applicants assert that the Examiner's statements regarding the use of attenuators are false. In contrast to the Examiner's assertion that "attenuators are well known in the art and are widely used

to reduce noise levels," Applicants assert that it is well known in optical communications systems that placing an attenuator at the input chain of optical components is detrimental when signal-to-noise ratio is important. Support for this assertion is found, for example, in the text Introduction to Communications Systems, by Ferrel G. Stremler, Addison-Wesley Publishing Company, 1977. In particular, at pages 170 – 174 (a copy of pages 170 – 174 is provided herewith as Appendix A), Example 4.4.6 shows that the noise figure of an attenuator increases with increased attenuation. Example 4.4.7 gives the well-known Friis formula showing that a chain of components has the best signal-to-noise ratio performance when the first component closest to the input signal has the lowest noise figure, that is, when the attenuation is the lowest. These examples directly contradict the Examiner's assertion that "attenuators are well known in the art and are widely used to reduce noise levels." In view of the above-identified evidence, the Examiner's assertion cannot be relied upon as the motivation behind the combination of references that is suggested by the Examiner.

Additionally, Applicants assert that Evans cannot be relied upon to provide the requisite motivation behind the suggested combination because there are fundamental differences between the electrical circuit taught by Evans and the claimed optical heterodyne detection systems and methods. As is known in the field of optical heterodyne detection, an input signal and local oscillator signal combine to create an optical signal having components that include intensity noise from the input signal and the heterodyne signal. The intensity noise from the input signal and the heterodyne signal scale differently with attenuation of the input signal. Specifically, when the noise of the combined optical signal is dominated by the intensity noise of the input signal, the intensity noise of the input signal is proportional to the power of the input signal (P_S). The relationship of the input signal intensity noise, I_N, to the power of the input signal is:

$$I_N \alpha \; P_S$$

On the other hand, the intensity of the heterodyne signal is proportional to the square root of the input signal, P_S. The relationship of the intensity of the heterodyne signal, I_H, to the power of the input signal is:

$$I_H \alpha \sqrt{P_s}$$

Because of the different scaling relationships between the intensity noise of the input signal and the heterodyne signal, attenuating the power of the input signal causes the intensity noise of the input signal to drop at a faster rate than the heterodyne signal. Because the intensity noise of the input signal drops at a faster rate than the heterodyne signal, the signal to noise ratio of the heterodyne signal (I_H/I_N) increases as the result of attenuation when the intensity noise of the input signal is the dominant noise source. The above-described relationship is explained in the text Fiber Optic Test and Measurement, by Dennis Derickson, Prentice Hall PTR, 1998. There is no equivalent relationship between signals taught in Evans. Because there is no equivalent relationship between signals taught in Evans, Applicants assert that it is improper to rely on Evans as the basis for the motivation behind the combination of references that is suggested by the examiner.

The proposed modification to Sorin would render the teachings of Sorin unsatisfactory for their intended purpose

Again, Applicants assume from the Examiner's statement, "[i]t would have been obvious ... to have positioned the attenuator of Sorin immediately after the input port and before the signal combination" (Final action page 3, item 2), that the Examiner is suggesting that it would have been obvious to change the position of the attenuator (240), as disclosed in Sorin, from fiber (223) to fiber (213). As stated above, the attenuator (240) in Fig. 3 of Sorin is located on the reference arm of the reflectometer in order to attenuate the reference signal because the power of the reference signal "is too large in comparison to the signal from device (12)." (col. 4, lines 46 – 47) That is, Sorin teaches that the purpose of the attenuator is to lower the power of the reference signal relative to the signal from the device under test (i.e., lower the ratio of reference signal power to the DUT signal power).

Applicants assert that modifying the reflectometer of Sorin by changing the position of the attenuator from fiber (223) to fiber (213), as proposed by the Examiner, would render the teachings of Sorin unsatisfactory for their intended purpose. It is well settled in the law that if the proposed modification would render the prior art invention being modified unsatisfactory for its intended purpose, then there is no suggestion or motivation to make the proposed modification. [MPEP 2143.01] Applicants assert that modifying the reflectometer of Sorin by moving the attenuator to fiber (213), as proposed by the Examiner, would render the teachings of

Sorin unsatisfactory for their intended purpose because changing the position of the attenuator to fiber (213) would not significantly lower the power of the reference signal relative to the signal from the device under test. Applicants assert that changing the position of the attenuator to fiber (213) would cause the initial signal to be attenuated and would simply lower the power of the reference signal (returned via fiber 223) and the signal from the device under test (returned via fiber 216) by equivalent amounts. Lowering the power of the reference signal and the signal from the device under test by equivalent amounts does not significantly change the ratio of the two signal powers when combined at the coupler (216) and therefore does not cause any improvement in the signal to noise ratio of the desired signal. Because the ratio of the two signal powers is not significantly changed by moving the position of the attenuator as proposed by the Examiner, Applicants assert that the modified reflectometer would not achieve a stated objective of providing a reflectometer with the complexity of a Michelson interferometer but improved signal to noise performance (col. 2, lines 11 – 19). As a result, the proposed modification to Sorin would render the system unsatisfactory for its intended purpose. Applicants assert that because modifying the reflectometer of Sorin by moving the attenuator would render the modified reflectometer unsatisfactory for its intended purpose, there is no suggestion or motivation to modify the reflectometer as stated by the Examiner and therefore claims 1, 11, and 14 are not rendered obvious from the AAPA and Sorin in view of Hasegawa and Evans.

There is no suggestion or motivation in Sorin to re-locate the attenuator

Applicants assert that the requisite suggestion or motivation to re-locate the attenuator in Sorin is not found in Sorin. As described above, the attenuator in Sorin is placed in a specific location for the specific, and stated, purpose of reducing the power of the reference signal because the power of the reference signal is too large in comparison to the signal from the device under test. Nowhere in Sorin is there a suggestion or motivation to move the attenuator to a different location. In particular, Sorin does not suggest that the attenuator should be positioned between the source (214) and the coupler (216) of Sorin.

Hasegawa does not provide the motivation behind the suggested combination

With regard to Hasegawa, the Office action simply points out the existence of the attenuator in Hasegawa and then concludes that it would have been obvious to combine Hasegawa with the AAPA and Sorin. The only support provided for the conclusion is the phrase "since the noise intensity from the input signal is usually the dominant noise source (fig. 8, ref. 62)." Applicants are not sure what is meant by the phrase "since the noise intensity from the input signal is usually a dominant noise source." Further, Applicants assert that identifying intensity noise that is contributed from an input signal as a dominant noise source in an optical heterodyne detection system does not provide the requisite suggestion or motivation to combine Hasegawa with the AAPA and Sorin or the use of attenuation on an input signal as recited in claim 1. It is well settled in the law that the mere fact that references can be combined does not render the resultant combination obvious unless the prior art also suggests the desirability of the combination. [M.P.E.P. 2143.01] Applicants assert that the general statement "since the noise intensity from the input signal is usually a dominant noise source" does not suggest the combination of the AAPA, Sorin, and Hasegawa without some objective reasons.

Sorin does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal

Claims 4 and 12 recite a method and system in which *the level of attenuation is adjusted in response to feedback from an output signal.* Applicants assert that Sorin does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal. Sorin discloses attenuators in the embodiments depicted in Figs. 3 and 5. However, the attenuators (240; 340) disclosed in Sorin are not connected to any feedback loop that receives feedback from an output signal. Additionally, Sorin does not disclose a process in which the level of attenuation is adjusted in response to feedback from an output signal. Because the attenuators are not connected to any feedback loop and because Sorin does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal, Applicants assert that claims 4 and 12 are not rendered obvious in view of Sorin.

Applicants note that Sorin does disclose an additional photodetector and a subtraction circuit (Fig. 5, 344 and 346) that are used "to detect the RIN and subtract it from the measured signal." Sorin discloses that the subtraction is done when the

RIN is very large and it is not "possible to sufficiently attenuate the reference signal sufficiently [to] make the RIN less than the shot noise without causing the signal to be dominated by the noise from the detector." (col. 5, lines 54 – 64). In particular, Sorin discloses measuring the light intensity from photodetector (344) and then subtracting the measured light intensity from the output of photodetector (327) via subtraction circuit (346). (col. 6, lines 7 – 10). However, Applicants assert that subtracting the output from two photodetectors using the subtraction circuit (346) does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal as recited in claims 4 and 12. Because Sorin does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal, Applicants assert that claims 4 and 12 are not rendered obvious in view of Sorin.

SUMMARY

Applicants assert that because there is no suggestion or motivation in the AAPA, Sorin, Hasegawa, or Evans or in the knowledge generally available to one of ordinary skill in the art to modify the AAPA and Sorin to include the teachings of Hasegawa and Evans and because Sorin would not work for its intended purpose if modified as suggest by the Examiner that a *prima facie* case of obviousness has not been made and claims 1, 11, and 14 are not rendered obvious from Sorin in view of Iwaoka.

For all the foregoing reasons, it is earnestly and respectfully requested that the Board of Patent Appeals and Interferences reverse the rejections of the Examiner regarding claims 1 – 20, so that this case may be allowed and pass to issue in a timely manner.

Respectfully submitted,

Date: December 2, 2003

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APPENDIX

1. A method for monitoring an optical signal utilizing optical heterodyne detection comprising steps of:

    providing an input signal;

    providing a local oscillator signal;

    attenuating said input signal;

    combining said attenuated input signal with said local oscillator signal to create a combined optical signal;

    detecting said combined optical signal; and

    generating an output signal that is indicative of an optical parameter of said input signal.

2. The method of claim 1 wherein said step of generating an output signal includes monitoring a heterodyne signal that is a component of said combined optical signal.

3. The method of claim 2 wherein said step of attenuating said input signal includes a step of attenuating said input signal to a level of attenuation that maximizes the signal to noise ratio of said heterodyne signal.

4. The method of claim 3 further including a step of adjusting said level of attenuation in response to feedback from said output signal in order to maximize said signal to noise ratio.

5. The method of claim 4 further including steps of measuring intensity noise of said input signal before said input signal is combined with said local oscillator signal, comparing said measured intensity noise of said input signal to the sum of all other noise sources related to said combined optical signal, and attenuating said input signal when said intensity noise of said input signal is the dominant noise source.

6. The method of claim 3 further including a step of adjusting said level of attenuation such that intensity noise from said input signal is approximately equal to shot noise from said local oscillator signal.

7. The method of claim 3 further including a step of adjusting said level of attenuation such that intensity noise from said input signal is equal to the sum of all other noises related to said combined optical signal.

8. The method of claim 3 further including a step of sweeping said local oscillator signal across a range of wavelengths in order to monitor said heterodyne signal.

9. The method of claim 1 wherein said step of generating an output signal includes a step of generating said output signal in a manner that is substantially independent of the polarization state of said input signal.

10. The method of claim 1 wherein said step of attenuating said input signal includes a step of completely blocking transmission of said input signal in order to calibrate an optical coupler or an optical receiver as a function of wavelength.

11. A method for monitoring an optical signal utilizing optical heterodyne detection comprising steps of:

providing an input signal;

providing a local oscillator signal;

attenuating said input signal before said input signal and said local oscillator signal are combined;

combining said attenuated input signal with said local oscillator signal to create a combined optical signal, said combined optical signal including a heterodyne signal, intensity noise from said input signal, and shot noise;

generating an electrical signal in response to said combined optical signal;

generating an output signal from said electrical signal that is indicative of an optical parameter of said input signal; and

adjusting the level of attenuation of said attenuated input signal to maximize the signal to noise ratio of said heterodyne signal.

12. The method of claim 11 wherein said step of generating an output signal includes a step of monitoring said heterodyne signal and wherein said level of attenuation is adjusted in response to feedback from said output signal.

13. The method of claim 12 wherein said level of attenuation is adjusted such that said intensity noise from said input signal is approximately equal to said shot noise signal.

14. A system for optical heterodyne detection comprising:

an attenuator having an input to receive an input signal and having an output for outputting an attenuated input signal;

an optical coupler having a first input and a second input, said first input being optically connected to said attenuator to receive said attenuated input signal, said second input receiving a local oscillator signal, said optical coupler having an output for outputting a combined optical signal that includes said input signal and said local oscillator signal; and

an optical receiver having an input for receiving said combined optical signal from said optical coupler and an output for outputting an electrical signal representative of said combined optical signal.

15. The system of claim 14 further including a processor for receiving said electrical signal from said optical receiver and generating an output signal that is indicative of an optical parameter of said input signal, wherein said processor monitors a heterodyne signal that is a component of said combined optical signal.

16. The system of claim 15 wherein said attenuator is an adjustable attenuator that allows for variable levels of input signal attenuation.

17. The system of claim 16 further including a feedback loop between said processor and said adjustable attenuator, wherein said level of attenuation of said input signal is adjusted to maximize the signal to noise ratio of the heterodyne signal.

18. The system of claim 17 further including a second optical receiver connected to receive a portion of said input signal before said input signal is received by said optical coupler, said second optical receiver being connected to transmit a measure of the intensity noise of said input signal to said processor.

19. The system of claim 16 further including a frequency counter connected to receive a portion of said local oscillator signal before said local oscillator signal is received by said optical coupler, said frequency counter being connected to transmit a measure of the frequency of said local oscillator signal to said processor.

20. The system of claim 15 wherein said optical coupler further includes a second output for outputting a portion of said combined optical signal to said optical receiver, said optical receiver enabling said output signal to be independent of the polarization state of said input signal and balanced with regard to intensity noise of said combined optical signal.

APPENDIX A

Pages 170 – 174 of Introduction to Communications Systems, by Ferrel G. Stremler, Addison-Wesley Publishing Company, 1977

Drill Problem 4.4.3 Compute the equivalent noise bandwidth of the (RC-type) filter whose magnitude transfer characteristic is $|H(\omega)| = 1/\sqrt{1 + \omega^2}$. Compare your result to the -3-dB bandwidth.

Answer. 0.250 Hz; 57% greater.
[*Note*: As the order of the filter increases, the -3-dB bandwidth and the noise equivalent bandwidth agree more closely.]

4.4.4 Available Power and Noise Temperature

From Eqs. (4.40) and (4.47), the thermal noise power generated in a resistor R is

$$P_n = 4kTB. \tag{4.58}$$

How much of this noise power can be extracted? Using a matched resistive load R (noise-free) for maximum power transfer, we find that the voltage transferred is exactly one-half of the open circuit voltage. The maximum available power, P_a, is then one-fourth that given in Eq. (4.58), or

$$P_a = kTB. \tag{4.59}$$

This available noise power, P_a, is the maximum thermal noise power that can be extracted from a noisy resistor.

Examining Eq. (4.59), we see that k is a constant and B is the equivalent noise bandwidth—constant for a given system. The temperature T is then directly related to the available noise power. A convenient way to describe the input noise power is to specify it as a noise temperature. Thus the ***noise temperature*** specifies the thermal noise power into a matched resistance.

The noise-free resistor used for matching purposes above is, of course, fictitious. In practice, we usually wish to connect an amplifier (receiver) which has an input resistance R for maximum power transfer. A simplified model of this amplifier is an input resistance R at an equivalent noise temperature T_e followed by a power gain G_p. In other words, the noise temperature T_e is the effective temperature of a white thermal noise source at the system input that would be required to produce the same noise power at the output of an equivalent noiseless system. Some very low-noise amplifiers, for example, have effective noise temperatures as low as 10 K to 30 K while standard broadcast receivers may have noise temperatures on the order of 1,000 K.

Note that the equivalent noise temperature is not the ambient temperature of the amplifier. Equivalent noise temperatures below ambient temperature are possible by use of amplifiers with a low resistive component in the gain characteristic (e.g., parametric amplifiers). Sometimes cryogenic cooling is also employed to lower the effective noise temperature.

Example 4.4.4 We wish to design a high-gain cascaded-stage amplifier. The first stage power gain is fixed at 20 dB. Succeeding stages have provisions for gain control but the maximum gain per stage is 20 dB. The maximum net power gain of the amplifier is to be such that the thermal noise power level from internally generated noise is 20 milliwatts at the output. Determine the minimum number of stages needed if $T_e = 600$ K, $B_N = 10$ MHz.†

S lution. The internally generated noise power in the first stage, referred to the input, is

$$\begin{aligned} P_a &= kT_eB \\ &= (1.38 \times 10^{-23})(600)(10^7) = 8.28 \times 10^{-14} \text{ watt.} \end{aligned}$$

After 20 dB of gain, this becomes 8.28×10^{-12} watt of noise power at the input to the second stage. The available input noise power to the second stage with the first stage disconnected would again be on the order of 8.28×10^{-14} watt. However, this is now almost negligible ($=1\%$) compared to the noise power coming from the first stage. Our conclusion, then, is that *the noise performance of cascaded amplifiers is primarily dependent only on the noise performance of the first stage if that stage has appreciable gain.*

The required maximum power gain, G_p [$G_p = |H(\omega_0|^2$] is

$$\begin{aligned} G_p &= P_o/P_a \\ &= 20 \times 10^{-3}/(8.28 \times 10^{-14}) = 2.42 \times 10^{11} \\ &\cong 114 \text{ dB}. \end{aligned}$$

Thus the amplifier will require a minimum of six (6) stages to meet the given specifications.

★4.4.5 Noise Figure

It is convenient to develop a concise way to state the equivalent noise temperature of an amplifier relative to a fixed standard. This leads to the definition of a noise figure which can then be used as a figure-of-merit in comparisons between amplifiers for low-level signals.

Let the input and output signal voltages (or currents) in a given system be $s_i(t)$, $s_o(t)$, respectively, and let the input and output noise voltages (or currents) be $n_i(t)$, $n_o(t)$. The input signal-to-noise ratio, $(S/N)_i$, is‡

$$(S/N)_i = \overline{s_i^2(t)}/\overline{n_i^2(t)}, \tag{4.60}$$

† The equivalent noise bandwidth does vary somewhat with the number of amplifier stages but we shall ignore this change here.

‡ The resistance factor drops out so that this is also a power ratio.

and the output signal-to-noise ratio is

$$(S/N)_o = \overline{s_o^2(t)}/\overline{n_o^2(t)}. \tag{4.61}$$

The system always adds some noise so that the input signal-to-noise ratio is higher than the output signal-to-noise ratio. To measure the amount of degradation, we define a noise figure, F, to be the ratio of the input signal-to-noise ratio divided by the output signal-to-noise ratio:

$$F \triangleq \frac{(S/N)_i}{(S/N)_o}. \tag{4.62}$$

By definition, the input noise power in Eq. (4.62) is equivalent to the thermal noise power provided by a resistor matched to the input and at a temperature of $T_0 = 290$ K. The noise figure of a perfect system is unity, and the introduction of additional noise causes the noise figure to be larger than one.

Some convenient simplifications can be made when only thermal noise is present in the system. Let us apply a signal $s_i(t)$ and thermal noise $n_i(t)$ at a temperature T_0 to the input of an amplifier with a power gain G_p and noise bandwidth B. The available input noise power is

$$N_i = kT_0B. \tag{4.63}$$

The output signal power is

$$S_o = S_iG_p. \tag{4.64}$$

The amplifier adds some thermal noise. Representing this noise by an equivalent noise temperature T_e referred to the amplifier input, we have

$$N_o = kT_0BG_p + kT_eBG_p. \tag{4.65}$$

Substituting Eqs. (4.63)–(4.65) into Eq. (4.62), the noise figure of the amplifier is

$$F = 1 + \frac{T_e}{T_0}. \tag{4.66}$$

This result is so simple and easy to apply that even if not all noise sources are thermal, the effects are often included in an equivalent noise temperature using test data.† It is quite common to express the noise figure in decibels:

$$F_{dB} = 10 \log_{10}(F).$$

Note that the noise figure of an ideal system which generates no noise itself is $F = 1$, and that portion of the noise figure of any system arising from internally generated noise is $(F - 1)$.

† The standard value for T_0 is 290 K.

Example 4.4.5 A given amplifier has a 4-dB noise figure, a noise bandwidth of 500 kHz, and an input resistance of 50 Ω. Calculate the rms signal input which yields an output signal-to-noise ratio of unity when the amplifier is connected to a 50-Ω input at 290 K.

Solution. The available input power is

$$P_n = kT_0B = 2.00 \times 10^{-15}\ \text{watt},$$

so that

$$\overline{n_i^2(t)} = P_nR = 1.00 \times 10^{-13}\ \text{volt}^2,$$
$$F = 4\ \text{dB} = 2.51.$$

Using Eq. (4.62), we have

$$(S/N)_i = F(S/N)_o = F.$$

The required input signal is

$$\overline{s_i^2(t)} = (2.51)(1.00 \times 10^{-13})\ \text{volt}^2$$
$$\sqrt{\overline{s_i^2(t)}} = 0.501\ \mu\text{V}.$$

Example 4.4.6 A resistive attenuator (e.g., a coaxial cable or waveguide) at a temperature T_0 has matched input and output resistances and an attenuation (in power) of α, where $\alpha > 1$. Determine the equivalent noise temperature and noise figure of the attenuator when the input source and the attenuator are at temperature T_0.

Solution. Using Eq. (4.65) and noting that $G_p = 1/\alpha$,

$$N_o = kT_0B(1/\alpha) + kT_eB(1/\alpha).$$

Looking back into the output terminals, the attenuator appears entirely resistive and at a temperature T_0 so that

$$N_o = kT_0B.$$

Equating these two expressions, we have

$$T_e = (\alpha - 1)T_0.$$

Use of Eq. (4.66) then yields

$$F = \alpha.$$

A similar procedure can be used if the attenuator is at some other temperature.

Example 4.4.7 A multistage amplifier has stage power gains $G_1, G_2, G_3, \ldots,$ and stage noise figures $F_1, F_2, F_3, \ldots,$ respectively. Show that the overall noise figure is

$$F = F_1 + [(F_2 - 1)/G_1] + [(F_3 - 1)/G_1G_2] + \cdots$$

and hence that the first stage is the most significant in the determination of the overall noise figure if $G_1 \gg 1$.

Solution. The result follows easily when one considers that the noise introduced by each stage is amplified only by the gains of that stage and succeeding stages. Assume a 3-stage amplifier with equivalent noise temperatures T_{e_1}, T_{e_2}, T_{e_3}:

$$
\begin{aligned}
S_o &= S_i G_1 G_2 G_3, \\
N_i &= kT_0 B, \\
N_o &= kT_0 B G_1 G_2 G_3 + kT_{e_1} B G_1 G_2 G_3 + kT_{e_2} B G_2 G_3 + kT_{e_3} B G_3 \\
&= N_i G_1 G_2 G_3 + (F_1 - 1) N_i G_1 G_2 G_3 + (F_2 - 1) N_i G_2 G_3 + (F_3 - 1) N_i G_3 \\
&= F_1 N_i G_1 G_2 G_3 + (F_2 - 1) N_i G_2 G_3 + (F_3 - 1) N_i G_3, \\
F &= \frac{S_i}{N_i} \Big/ \frac{S_o}{N_o} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}.
\end{aligned}
$$

Extensions of this result are straightforward.

This result demonstrates the advantages of using a first stage of amplification with not only a low noise figure (F_1) but also high gain (G_1). From Example 4.4.6 we see that the performance of a lossy transmission line fails on both counts. Therefore some amplification with low-noise stages is often used near or at the antenna in low-noise receiving systems before the signal is transferred (via a transmission line) to the main receiver.

Drill Problem 4.4.4 A receiver for geostationary satellite transmissions at 2 GHz consists of an antenna preamplifier with a noise temperature of 124 K and a gain of 20 dB. This is followed by an amplifier with a noise figure of 12 dB and a gain of 80 dB. Compute the overall noise figure and equivalent noise temperature of the receiver.

Answer. 2.0 dB; 170 K.

When an antenna is connected to the input of a receiver, it is convenient to represent it by a resistor which is matched to the receiver input and whose temperature represents the effective noise of the sky and the surrounding noise environment as seen through the antenna. This antenna temperature will in most cases differ substantially from 290 K.

If the input resistor, now representing an antenna, is at some arbitrary temperature T_a, we can modify Eq. (4.66) to give

$$
\begin{aligned}
N_o &= kT_a B G_p + kT_e B G_p, \\
N_o &= kB(T_a + T_e) G_p. \qquad (4.67)
\end{aligned}
$$

The equivalent noise temperature of an antenna is therefore easy to interpret and can be compared directly with the receiver noise temperature. Note that when T_a

and T_e contribute equally to the output noise, the largest possible improvement by going to a perfect receiver amounts to only a factor of two in signal-to-noise improvement. Therefore efforts to obtain a low-equivalent noise temperature in a receiver really pay large dividends only if the antenna noise temperature is low.

Average antenna noise temperatures are mainly a function of frequency and the pointing of the antenna. A graph illustrating some of the main sources of antenna noise temperature is shown in Fig. 4.13. Although the concept of noise figure is useful for the testing and comparisons of receivers, the concept of equivalent noise temperature is more useful in computations of actual system performance.

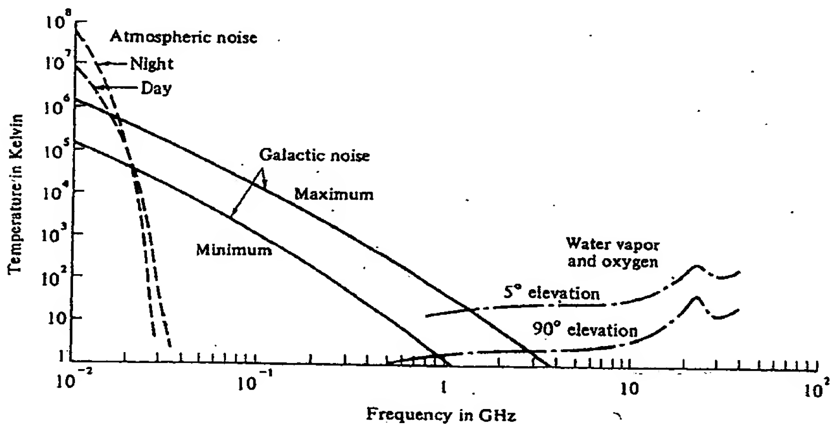

Fig. 4.13 Some average sky noise temperatures.

The principal source of antenna noise below 30 MHz is atmospheric noise which results mainly from lightning discharges. Propagation effects which make long-distance communication possible at these lower frequencies also provide good propagation for electrical storm activities occurring throughout the world. Galactic or cosmic noise is a major contributor above 30 MHz and up to the GHz range. This noise arises from radiation from outer space; for narrow beamwidths, the intensity of galactic noise is a function of antenna pointing direction. Our sun is also an active source of radiation but its effects are more localized in angular direction.

Water vapor and oxygen act as attenuators of rf energy, particularly around 23 GHz. These attenuation effects not only decrease signal strength but also act as thermal noise sources (see Example 4.4.6). The frequency range between about 2 to 8 GHz, bounded by the effects of galactic noise and noise due to oxygen and water vapor, is referred to as the "low-noise window." This is a preferred range for low-noise receivers for space telemetry and radio telescopes.

Attorney Docket No. 10991682-1 PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

Appellant: Sorin et al.
Serial No. 09/488,149
Filed: January 20, 2000
Group Art Unit: 2878
Examiner: Wang, George
For: SYSTEM AND METHOD FOR OPTICAL HETERODYNE DETECTION OF AN OPTICAL SIGNAL THAT UTILIZES OPTICAL ATTENUATION

Assistant Commissioner for Patents
Washington, D.C. 20231

BRIEF ON APPEAL

Sir:

This brief is in furtherance of Applicants' Notice of Appeal filed October 2, 2003, appealing the decision of the Examiner dated August 26, 2003 finally rejecting claims 1 – 20. A copy of the claims appears in the Appendix to this brief. This brief is transmitted in triplicate.

CERTIFICATE OF MAILING UNDER 37 C.F.R. 1.8

I hereby certify that this paper (along with any paper referred to as being attached or enclosed) is being deposited with the United States Postal Service on the date shown below with sufficient postage as "U.S. Express Mail" in an envelope addressed to: Assistant Commissioner for Patents, Washington, D.C. 20231

Date: December 2, 2003 Signed: Mark A. Wilson

Express Mail Label No.: ER 264470957US Typed Name: Mark A. Wilson

I. Real Party in Interest

The real party in interest in this appeal is Agilent Technologies, Inc., a Delaware Corporation, having a place of business at 395 Page Mill Road, Palo Alto, California 94303.

II. Related Appeals and Interferencs

There are currently no related appeals or interference proceedings in progress that will directly affect, or be directly affected by, or have a bearing on the Board's decision in the present Appeal.

III. Status of Claims

Claims 1 – 4, 11, 12, 14, and 15 were rejected under 35 U.S.C. 103(a) as being unpatentable over AAPA (Applicant's Admission of Prior Art) and Sorin (U.S. Patent No. 5,365,335) in view of Hasegawa et al. (U.S. Patent No. 4,553,264, hereinafter Hasegawa) and Evans et al. (U.S. Patent No. 4,048,573, hereinafter Evans).

Claims 1 – 20 were originally filed with the application. No claims have been amended, canceled, or added. This Appeal is made with regard to pending claims 1 – 20.

IV. Status of Amendments

There are no pending amendments.

V. Summary of the Invention

The claimed invention involves methods and systems for characterizing an optical signal utilizing optical heterodyne detection. The methods and systems, as recited in independent claims 1, 11, and 14, involve attenuating an input signal, combining the attenuated input signal with a local oscillator signal and detecting the combined optical signal. The input signal is attenuated before being combined with the local oscillator signal in order to improve the signal to noise ratio of the

heterodyne signal that is generated when the combined optical signal is detected. The signal to noise ratio of the heterodyne signal improves with attenuation of the input signal, specifically in the case where the intensity noise from the input signal is the dominant noise source, because the heterodyne signal and the intensity noise of the input signal scale differently with attenuation of the input signal.

A method for monitoring an optical signal utilizing optical heterodyne detection, as recited in claim 1, includes providing an input signal and a local oscillator signal and attenuating the input signal. The attenuated input signal is combined with the local oscillator signal to create a combined optical signal. The combined optical signal is detected and an output signal that is indicative of an optical parameter of the input signal is generated. In an embodiment of the method, the level of attenuation of the input signal is adjusted to maximize the signal to noise ratio of the heterodyne signal.

Another method for monitoring an optical signal utilizing optical heterodyne detection, as recited in claim 11, includes providing an input signal and a local oscillator signal and attenuating the input signal before the input signal and the local oscillator signal are combined. The attenuated input signal is then combined with the local oscillator signal to create a combined optical signal. The combined optical signal includes a heterodyne signal, intensity noise from the input signal, and shot noise. An electrical signal is generated in response to the combined optical signal. An output signal that is indicative of an optical parameter of the input signal is generated from the electrical signal. Additionally, the level of attenuation of the input signal is adjusted to maximize the signal to noise ratio of the heterodyne signal.

An embodiment of an optical heterodyne detection system, as recited in claim 14, includes an attenuator (224), an optical coupler (210), and a receiver (212). The attenuator has an input to receive an input signal (202) and an output for outputting an attenuated input signal. The optical coupler has a first input that is optically connected to the attenuator to receive the attenuated input signal and a second input that receives a local oscillator signal (206). The optical coupler combines the attenuated input signal and the local oscillator signal to create a combined optical signal and outputs the combined optical signal through an output. The optical receiver receives the combined optical signal from the optical coupler and generates an electrical signal that is representative of the combined optical signal.

An embodiment of the optical heterodyne detection system also includes a processor (216) that utilizes the electrical signal from the receiver (212) to generate an output signal that is indicative of an optical parameter of the input signal (202). The processor monitors the heterodyne signal that is a component of the combined optical signal in order to generate the output signal.

In an embodiment of the optical heterodyne detection system, the attenuator (224) is adjustable so that the input signal can be attenuated to different levels. Preferably, the attenuator is adjusted to attenuate the input signal to a level that maximizes the signal to noise ratio of the heterodyne signal. In an embodiment, the signal to noise ratio is maximized when the intensity noise of input signal is approximately equal to the shot noise of the local oscillator signal. A feedback loop (226) may be provided between the processor and the adjustable attenuator so that the attenuator can be adjusted in response to real-time measurements of the signal to noise ratio of the heterodyne signal.

Before utilizing the system to measure an input signal it may be necessary to calibrate the system. The attenuator may be utilized to block transmission of the input signal so that the optical coupler and the receiver can be calibrated.

VI. Issues

Whether claims 1 – 4, 11, 12, 14, and 15 are obvious under 35 U.S.C. 103(a) as being unpatentable over the AAPA and Sorin in view of Hasegawa and Evans.

VII. Grouping of Claims for Each Contested Ground of Rejection

Regarding the rejection under 35 U.S.C. 103(a), claims 1 – 3, 11, 14, and 15 stand or fall together and claims 4 and 12 stand or fall together. Reasons why claims 4 and 12 are believed to be separately patentable are explained in the Argument section.

VIII. Argument

Applicants maintain that the Examiner has failed to make a *prima facie* case of obviousness under 35 U.S.C. 103(a) which requires that three basic criteria must be met, as set forth in M.P.E.P 2142:

> "First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art reference (or references when combined) must teach or suggest all of the claim limitations."

The initial burden is therefore on the Examiner to establish a *prima facie* case of obviousness under 35 U.S.C. 103(a).

Applicants assert that claims 1 – 4, 11, 12, 14, and 15 are not rendered obvious from AAPA and Sorin in view of Hasegawa and Evans because a *prima facie* case of obviousness has not been established. Applicants assert that a *prima facie* case of obviousness has not been established because the Examiner has not presented some suggestion or motivation, either in the references themselves, or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine the reference teachings. In addition, with regard to claims 4 and 12, Applicants assert that even if the prior art references were combined, the combined references fail to teach or suggest all of the claim limitations.

Background on the AAPA, Sorin, Hasewaga, and Evans

Applicants disclose a known optical heterodyne detection system in Fig. 1 of the specification. The optical heterodyne detection system includes an input waveguide (104), a local oscillator waveguide (108), an optical coupler (110), an output waveguide (118), an optical receiver (112), and a signal processor (116).

Sorin discloses a "low-coherence reflectometer for use in measuring backscattering." (Abstract) That is, Sorin discloses a reflectometer that is used to measure the optical properties (specifically, the reflective properties) of a device. The device, whose optical properties are being measured by the reflectometer, is often referred to as the device under test or "DUT".

The reflectometer disclosed by Sorin in Fig. 3 includes a light source (214), a coupler (216), a device under test (12), an attenuator (240), mirrors (224 and 231), a detector (227), and an analyzer (219). The purpose of the attenuator in the reflectometer disclosed by Sorin is to attenuate the reference signal. According to Sorin, the reference signal is attenuated because the power of the reference signal returned via fiber (223), in many cases of interest, is too large in comparison to the signal from the device under test (12) (the backscattered light). (col. 4, lines 39 – 48) As stated in Sorin at col. 5, lines 16 – 18, "according to the present invention, the reference power is decreased by including an attenuator in the reference *and* of the interferometer." (Applicants assume that the word "and" was a translation error and that the word should be read as "end")

Hasegawa discloses a double superheterodyne tuner used for the VHF and/or UHF band (col. 1, lines 5 – 9).

Evans discloses improvements in high fidelity electrical amplifiers to minimize clipping.

<u>Basis of Rejection for Obviousness</u>

The Final action of August 26, 2003 states that the AAPA and Sorin disclose "a device and method of monitoring an optical signal utilizing a heterodyne detection (fig. 3, ref. 200) comprising steps of providing an input signal (fig. 3, ref. 214), a local oscillator signal (fig. 3, ref. 220), combining them (fig. 3, ref. 216), detecting the combined signal (fig. 3, ref. 12) of heterodyne, intensity and shot noise, and generating an output signal that is indicative of an optical parameter of input signal and includes monitoring a heterodyne signal." The Final action goes on to state that the "AAPA and Sorin fail to disclose an attenuator positioned before heterodyne signal combination" (Final action, August 26, 2003, page 3, item 2) but that "Hasegawa discloses a heterodyne tuner with an attenuator positioned immediately after the input (fig. 8, ref. 62)" and that "Evans discloses amplification improvements that include attenuation at the input (fig. 1; abstract)." The Office action concludes that it would have been obvious "to have positioned the attenuator of Sorin immediately after the input port and before the signal combination as suggested by Hasegawa since the noise intensity from the input signal is usually a dominant noise source (fig. 8, ref. 62)." (Office action page 3, item 2) From this statement, Applicants assume that the Examiner is suggesting that it would have been obvious to

change the position of the attenuator (240), as disclosed in Fig. 3 of Sorin, from fiber (223) to fiber (213) such that the attenuator is located between the light source (214) and the coupler (216). The Final action goes on to state:

> "Although the placing the attenuator immediately following the input signal achieves the same functional purpose as placing it after the coupler to provide attenuation feedback, it is clear that placing it at the site of dominant noise generation would render it more advantageous and beneficial because attenuators are well known in the art and are widely used to reduce noise levels. Therefore, maximizing signal to noise ratio at the dominant noise source would have been obvious to do for any optical system (Evans, abstract)."

<u>Evans does not provide the motivation behind the suggested combination</u>

Applicants assert that the Office action does not identify a suggestion or motivation either in the AAPA, Sorin, Hasegawa, Evans or in the knowledge generally available to one of ordinary skill in the art, to combine Hasegawa and Evans with the AAPA and Sorin. Specifically, with regard to Evans, Applicants assert that the Examiner has relied upon false assumptions as the basis for the motivation behind the suggested combination.

In reference to Evans, the Final action states that "Evans discloses amplification improvements that include attenuation at the input (fig. 1, Abstract)." The Final action goes on to state that "[a]ttenuators are well known in the art and are widely used to reduce noise levels", and "[t]herefore, maximizing signal to noise ratio at the dominant noise source would have been obvious to do for any optical system (Evans, abstract)." In the "Response to Arguments" section of the August 26, 2003 Final action, the Examiner states:

> "So Examiner argues that the statement that attenuators are well known in the art and widely used to reduce noise levels is relevant, especially in light of the Evans reference, which is directed toward attenuation at the input. For this reason, it is clear that an attenuator is not only able to reduce noise levels or maximize signal to noise ratio, but able to do so at the input or dominant noise source. This is the motivation behind the suggestive combination that Applicant has misinterpreted."

In response to the above-identified quotations, Applicants assert that the Examiner's statements regarding the use of attenuators are false. In contrast to the Examiner's assertion that "attenuators are well known in the art and are widely used

to reduce noise levels," Applicants assert that it is well known in optical communications systems that placing an attenuator at the input chain of optical components is detrimental when signal-to-noise ratio is important. Support for this assertion is found, for example, in the text Introduction to Communications Systems, by Ferrel G. Stremler, Addison-Wesley Publishing Company, 1977. In particular, at pages 170 – 174 (a copy of pages 170 – 174 is provided herewith as Appendix A), Example 4.4.6 shows that the noise figure of an attenuator increases with increased attenuation. Example 4.4.7 gives the well-known Friis formula showing that a chain of components has the best signal-to-noise ratio performance when the first component closest to the input signal has the lowest noise figure, that is, when the attenuation is the lowest. These examples directly contradict the Examiner's assertion that "attenuators are well known in the art and are widely used to reduce noise levels." In view of the above-identified evidence, the Examiner's assertion cannot be relied upon as the motivation behind the combination of references that is suggested by the Examiner.

Additionally, Applicants assert that Evans cannot be relied upon to provide the requisite motivation behind the suggested combination because there are fundamental differences between the electrical circuit taught by Evans and the claimed optical heterodyne detection systems and methods. As is known in the field of optical heterodyne detection, an input signal and local oscillator signal combine to create an optical signal having components that include intensity noise from the input signal and the heterodyne signal. The intensity noise from the input signal and the heterodyne signal scale differently with attenuation of the input signal. Specifically, when the noise of the combined optical signal is dominated by the intensity noise of the input signal, the intensity noise of the input signal is proportional to the power of the input signal (P_S). The relationship of the input signal intensity noise, I_N, to the power of the input signal is:

$$I_N \alpha \; P_S$$

On the other hand, the intensity of the heterodyne signal is proportional to the square root of the input signal, P_S. The relationship of the intensity of the heterodyne signal, I_H, to the power of the input signal is:

$$I_H \alpha \; \sqrt{P_s}$$

Because of the different scaling relationships between the intensity noise of the input signal and the heterodyne signal, attenuating the power of the input signal causes the intensity noise of the input signal to drop at a faster rate than the heterodyne signal. Because the intensity noise of the input signal drops at a faster rate than the heterodyne signal, the signal to noise ratio of the heterodyne signal (I_H/I_N) increases as the result of attenuation when the intensity noise of the input signal is the dominant noise source. The above-described relationship is explained in the text Fiber Optic Test and Measurement, by Dennis Derickson, Prentice Hall PTR, 1998. There is no equivalent relationship between signals taught in Evans. Because there is no equivalent relationship between signals taught in Evans, Applicants assert that it is improper to rely on Evans as the basis for the motivation behind the combination of references that is suggested by the examiner.

The proposed modification to Sorin would render the teachings of Sorin unsatisfactory for their intended purpose

Again, Applicants assume from the Examiner's statement, "[i]t would have been obvious ... to have positioned the attenuator of Sorin immediately after the input port and before the signal combination" (Final action page 3, item 2), that the Examiner is suggesting that it would have been obvious to change the position of the attenuator (240), as disclosed in Sorin, from fiber (223) to fiber (213). As stated above, the attenuator (240) in Fig. 3 of Sorin is located on the reference arm of the reflectometer in order to attenuate the reference signal because the power of the reference signal "is too large in comparison to the signal from device (12)." (col. 4, lines 46 – 47) That is, Sorin teaches that the purpose of the attenuator is to lower the power of the reference signal relative to the signal from the device under test (i.e., lower the ratio of reference signal power to the DUT signal power).

Applicants assert that modifying the reflectometer of Sorin by changing the position of the attenuator from fiber (223) to fiber (213), as proposed by the Examiner, would render the teachings of Sorin unsatisfactory for their intended purpose. It is well settled in the law that if the proposed modification would render the prior art invention being modified unsatisfactory for its intended purpose, then there is no suggestion or motivation to make the proposed modification. [MPEP 2143.01] Applicants assert that modifying the reflectometer of Sorin by moving the attenuator to fiber (213), as proposed by the Examiner, would render the teachings of

Sorin unsatisfactory for their intended purpose because changing the position of the attenuator to fiber (213) would not significantly lower the power of the reference signal relative to the signal from the device under test. Applicants assert that changing the position of the attenuator to fiber (213) would cause the initial signal to be attenuated and would simply lower the power of the reference signal (returned via fiber 223) and the signal from the device under test (returned via fiber 216) by equivalent amounts. Lowering the power of the reference signal and the signal from the device under test by equivalent amounts does not significantly change the ratio of the two signal powers when combined at the coupler (216) and therefore does not cause any improvement in the signal to noise ratio of the desired signal. Because the ratio of the two signal powers is not significantly changed by moving the position of the attenuator as proposed by the Examiner, Applicants assert that the modified reflectometer would not achieve a stated objective of providing a reflectometer with the complexity of a Michelson interferometer but improved signal to noise performance (col. 2, lines 11 – 19). As a result, the proposed modification to Sorin would render the system unsatisfactory for its intended purpose. Applicants assert that because modifying the reflectometer of Sorin by moving the attenuator would render the modified reflectometer unsatisfactory for its intended purpose, there is no suggestion or motivation to modify the reflectometer as stated by the Examiner and therefore claims 1, 11, and 14 are not rendered obvious from the AAPA and Sorin in view of Hasegawa and Evans.

There is no suggestion or motivation in Sorin to re-locate the attenuator

Applicants assert that the requisite suggestion or motivation to re-locate the attenuator in Sorin is not found in Sorin. As described above, the attenuator in Sorin is placed in a specific location for the specific, and stated, purpose of reducing the power of the reference signal because the power of the reference signal is too large in comparison to the signal from the device under test. Nowhere in Sorin is there a suggestion or motivation to move the attenuator to a different location. In particular, Sorin does not suggest that the attenuator should be positioned between the source (214) and the coupler (216) of Sorin.

Hasegawa does not provide the motivation behind the suggested combination

With regard to Hasegawa, the Office action simply points out the existence of the attenuator in Hasegawa and then concludes that it would have been obvious to combine Hasegawa with the AAPA and Sorin. The only support provided for the conclusion is the phrase "since the noise intensity from the input signal is usually the dominant noise source (fig. 8, ref. 62)." Applicants are not sure what is meant by the phrase "since the noise intensity from the input signal is usually a dominant noise source." Further, Applicants assert that identifying intensity noise that is contributed from an input signal as a dominant noise source in an optical heterodyne detection system does not provide the requisite suggestion or motivation to combine Hasegawa with the AAPA and Sorin or the use of attenuation on an input signal as recited in claim 1. It is well settled in the law that the mere fact that references can be combined does not render the resultant combination obvious unless the prior art also suggests the desirability of the combination. [M.P.E.P. 2143.01] Applicants assert that the general statement "since the noise intensity from the input signal is usually a dominant noise source" does not suggest the combination of the AAPA, Sorin, and Hasegawa without some objective reasons.

Sorin does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal

Claims 4 and 12 recite a method and system in which *the level of attenuation is adjusted in response to feedback from an output signal.* Applicants assert that Sorin does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal. Sorin discloses attenuators in the embodiments depicted in Figs. 3 and 5. However, the attenuators (240; 340) disclosed in Sorin are not connected to any feedback loop that receives feedback from an output signal. Additionally, Sorin does not disclose a process in which the level of attenuation is adjusted in response to feedback from an output signal. Because the attenuators are not connected to any feedback loop and because Sorin does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal, Applicants assert that claims 4 and 12 are not rendered obvious in view of Sorin.

Applicants note that Sorin does disclose an additional photodetector and a subtraction circuit (Fig. 5, 344 and 346) that are used "to detect the RIN and subtract it from the measured signal." Sorin discloses that the subtraction is done when the

RIN is very large and it is not "possible to sufficiently attenuate the reference signal sufficiently [to] make the RIN less than the shot noise without causing the signal to be dominated by the noise from the detector." (col. 5, lines 54 – 64). In particular, Sorin discloses measuring the light intensity from photodetector (344) and then subtracting the measured light intensity from the output of photodetector (327) via subtraction circuit (346). (col. 6, lines 7 – 10). However, Applicants assert that subtracting the output from two photodetectors using the subtraction circuit (346) does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal as recited in claims 4 and 12. Because Sorin does not teach or suggest adjusting the level of attenuation in response to feedback from an output signal, Applicants assert that claims 4 and 12 are not rendered obvious in view of Sorin.

SUMMARY

Applicants assert that because there is no suggestion or motivation in the AAPA, Sorin, Hasegawa, or Evans or in the knowledge generally available to one of ordinary skill in the art to modify the AAPA and Sorin to include the teachings of Hasegawa and Evans and because Sorin would not work for its intended purpose if modified as suggest by the Examiner that a *prima facie* case of obviousness has not been made and claims 1, 11, and 14 are not rendered obvious from Sorin in view of Iwaoka.

For all the foregoing reasons, it is earnestly and respectfully requested that the Board of Patent Appeals and Interferences reverse the rejections of the Examiner regarding claims 1 – 20, so that this case may be allowed and pass to issue in a timely manner.

Respectfully submitted,

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APPENDIX

1. A method for monitoring an optical signal utilizing optical heterodyne detection comprising steps of:

    providing an input signal;

    providing a local oscillator signal;

    attenuating said input signal;

    combining said attenuated input signal with said local oscillator signal to create a combined optical signal;

    detecting said combined optical signal; and

    generating an output signal that is indicative of an optical parameter of said input signal.

2. The method of claim 1 wherein said step of generating an output signal includes monitoring a heterodyne signal that is a component of said combined optical signal.

3. The method of claim 2 wherein said step of attenuating said input signal includes a step of attenuating said input signal to a level of attenuation that maximizes the signal to noise ratio of said heterodyne signal.

4. The method of claim 3 further including a step of adjusting said level of attenuation in response to feedback from said output signal in order to maximize said signal to noise ratio.

5. The method of claim 4 further including steps of measuring intensity noise of said input signal before said input signal is combined with said local oscillator signal, comparing said measured intensity noise of said input signal to the sum of all other noise sources related to said combined optical signal, and attenuating said input signal when said intensity noise of said input signal is the dominant noise source.

6. The method of claim 3 further including a step of adjusting said level of attenuation such that intensity noise from said input signal is approximately equal to shot noise from said local oscillator signal.

7. The method of claim 3 further including a step of adjusting said level of attenuation such that intensity noise from said input signal is equal to the sum of all other noises related to said combined optical signal.

8. The method of claim 3 further including a step of sweeping said local oscillator signal across a range of wavelengths in order to monitor said heterodyne signal.

9. The method of claim 1 wherein said step of generating an output signal includes a step of generating said output signal in a manner that is substantially independent of the polarization state of said input signal.

10. The method of claim 1 wherein said step of attenuating said input signal includes a step of completely blocking transmission of said input signal in order to calibrate an optical coupler or an optical receiver as a function of wavelength.

11. A method for monitoring an optical signal utilizing optical heterodyne detection comprising steps of:

providing an input signal;

providing a local oscillator signal;

attenuating said input signal before said input signal and said local oscillator signal are combined;

combining said attenuated input signal with said local oscillator signal to create a combined optical signal, said combined optical signal including a heterodyne signal, intensity noise from said input signal, and shot noise;

generating an electrical signal in response to said combined optical signal;

generating an output signal from said electrical signal that is indicative of an optical parameter of said input signal; and

adjusting the level of attenuation of said attenuated input signal to maximize the signal to noise ratio of said heterodyne signal.

12. The method of claim 11 wherein said step of generating an output signal includes a step of monitoring said heterodyne signal and wherein said level of attenuation is adjusted in response to feedback from said output signal.

13. The method of claim 12 wherein said level of attenuation is adjusted such that said intensity noise from said input signal is approximately equal to said shot noise signal.

14. A system for optical heterodyne detection comprising:

an attenuator having an input to receive an input signal and having an output for outputting an attenuated input signal;

an optical coupler having a first input and a second input, said first input being optically connected to said attenuator to receive said attenuated input signal, said second input receiving a local oscillator signal, said optical coupler having an output for outputting a combined optical signal that includes said input signal and said local oscillator signal; and

an optical receiver having an input for receiving said combined optical signal from said optical coupler and an output for outputting an electrical signal representative of said combined optical signal.

15. The system of claim 14 further including a processor for receiving said electrical signal from said optical receiver and generating an output signal that is indicative of an optical parameter of said input signal, wherein said processor monitors a heterodyne signal that is a component of said combined optical signal.

16. The system of claim 15 wherein said attenuator is an adjustable attenuator that allows for variable levels of input signal attenuation.

17. The system of claim 16 further including a feedback loop between said processor and said adjustable attenuator, wherein said level of attenuation of said input signal is adjusted to maximize the signal to noise ratio of the heterodyne signal.

18. The system of claim 17 further including a second optical receiver connected to receive a portion of said input signal before said input signal is received by said optical coupler, said second optical receiver being connected to transmit a measure of the intensity noise of said input signal to said processor.

19. The system of claim 16 further including a frequency counter connected to receive a portion of said local oscillator signal before said local oscillator signal is received by said optical coupler, said frequency counter being connected to transmit a measure of the frequency of said local oscillator signal to said processor.

20. The system of claim 15 wherein said optical coupler further includes a second output for outputting a portion of said combined optical signal to said optical receiver, said optical receiver enabling said output signal to be independent of the polarization state of said input signal and balanced with regard to intensity noise of said combined optical signal.

APPENDIX A

Pages 170 – 174 of Introduction to Communications Systems, by Ferrel G. Stremler, Addison-Wesley Publishing Company, 1977

Drill Problem 4.4.3 Compute the equivalent noise bandwidth of the (RC-type) filter whose magnitude transfer characteristic is $|H(\omega)| = 1/\sqrt{1+\omega^2}$. Compare your result to the -3-dB bandwidth.

Answer. 0.250 Hz; 57% greater.
[*Note*: As the order of the filter increases, the -3-dB bandwidth and the noise equivalent bandwidth agree more closely.]

4.4.4 Available Power and Noise Temperature

From Eqs. (4.40) and (4.47), the thermal noise power generated in a resistor R is

$$P_n = 4kTB. \tag{4.58}$$

How much of this noise power can be extracted? Using a matched resistive load R (noise-free) for maximum power transfer, we find that the voltage transferred is exactly one-half of the open circuit voltage. The maximum available power, P_a, is then one-fourth that given in Eq. (4.58), or

$$P_a = kTB. \tag{4.59}$$

This available noise power, P_a, is the maximum thermal noise power that can be extracted from a noisy resistor.

Examining Eq. (4.59), we see that k is a constant and B is the equivalent noise bandwidth—constant for a given system. The temperature T is then directly related to the available noise power. A convenient way to describe the input noise power is to specify it as a noise temperature. Thus the *noise temperature* specifies the thermal noise power into a matched resistance.

The noise-free resistor used for matching purposes above is, of course, fictitious. In practice, we usually wish to connect an amplifier (receiver) which has an input resistance R for maximum power transfer. A simplified model of this amplifier is an input resistance R at an equivalent noise temperature T_e followed by a power gain G_p. In other words, the noise temperature T_e is the effective temperature of a white thermal noise source at the system input that would be required to produce the same noise power at the output of an equivalent noiseless system. Some very low-noise amplifiers, for example, have effective noise temperatures as low as 10 K to 30 K while standard broadcast receivers may have noise temperatures on the order of 1,000 K.

Note that the equivalent noise temperature is not the ambient temperature of the amplifier. Equivalent noise temperatures below ambient temperature are possible by use of amplifiers with a low resistive component in the gain characteristic (e.g., parametric amplifiers). Sometimes cryogenic cooling is also employed to lower the effective noise temperature.

Exampl 4.4.4 We wish to design a high-gain cascaded-stage amplifier. The first stage power gain is fixed at 20 dB. Succeeding stages have provisions for gain control but the maximum gain per stage is 20 dB. The maximum net power gain of the amplifier is to be such that the thermal noise power level from internally generated noise is 20 milliwatts at the output. Determine the minimum number of stages needed if $T_e = 600$ K, $B_N = 10$ MHz.†

Solution. The internally generated noise power in the first stage, referred to the input, is

$$P_a = kT_eB$$
$$= (1.38 \times 10^{-23})(600)(10^7) = 8.28 \times 10^{-14} \text{ watt.}$$

After 20 dB of gain, this becomes 8.28×10^{-12} watt of noise power at the input to the second stage. The available input noise power to the second stage with the first stage disconnected would again be on the order of 8.28×10^{-14} watt. However, this is now almost negligible ($= 1\%$) compared to the noise power coming from the first stage. Our conclusion, then, is that *the noise performance of cascaded amplifiers is primarily dependent only on the noise performance of the first stage if that stage has appreciable gain.*

The required maximum power gain, G_p [$G_p = |H(\omega_0|^2$] is

$$G_p = P_o/P_a$$
$$= 20 \times 10^{-3}/(8.28 \times 10^{-14}) = 2.42 \times 10^{11}$$
$$\cong 114 \text{ dB.}$$

Thus the amplifier will require a minimum of six (6) stages to meet the given specifications.

★4.4.5 Noise Figure

It is convenient to develop a concise way to state the equivalent noise temperature of an amplifier relative to a fixed standard. This leads to the definition of a noise figure which can then be used as a figure-of-merit in comparisons between amplifiers for low-level signals.

Let the input and output signal voltages (or currents) in a given system be $s_i(t)$, $s_o(t)$, respectively, and let the input and output noise voltages (or currents) be $n_i(t)$, $n_o(t)$. The input signal-to-noise ratio, $(S/N)_i$, is‡

$$(S/N)_i = \overline{s_i^2(t)}/\overline{n_i^2(t)}, \tag{4.60}$$

† The equivalent noise bandwidth does vary somewhat with the number of amplifier stages but we shall ignore this change here.

‡ The resistance factor drops out so that this is also a power ratio.

and the output signal-to-noise ratio is

$$(S/N)_o = \overline{s_o^2(t)}/\overline{n_o^2(t)}. \tag{4.61}$$

The system always adds some noise so that the input signal-to-noise ratio is higher than the output signal-to-noise ratio. To measure the amount of degradation, we define a noise figure, F, to be the ratio of the input signal-to-noise ratio divided by the output signal-to-noise ratio:

$$F \triangleq \frac{(S/N)_i}{(S/N)_o}. \tag{4.62}$$

By definition, the input noise power in Eq. (4.62) is equivalent to the thermal noise power provided by a resistor matched to the input and at a temperature of $T_0 = 290$ K. The noise figure of a perfect system is unity, and the introduction of additional noise causes the noise figure to be larger than one.

Some convenient simplifications can be made when only thermal noise is present in the system. Let us apply a signal $s_i(t)$ and thermal noise $n_i(t)$ at a temperature T_0 to the input of an amplifier with a power gain G_p and noise bandwidth B. The available input noise power is

$$N_i = kT_0B. \tag{4.63}$$

The output signal power is

$$S_o = S_iG_p. \tag{4.64}$$

The amplifier adds some thermal noise. Representing this noise by an equivalent noise temperature T_e referred to the amplifier input, we have

$$N_o = kT_0BG_p + kT_eBG_p. \tag{4.65}$$

Substituting Eqs. (4.63)–(4.65) into Eq. (4.62), the noise figure of the amplifier is

$$F = 1 + \frac{T_e}{T_0}. \tag{4.66}$$

This result is so simple and easy to apply that even if not all noise sources are thermal, the effects are often included in an equivalent noise temperature using test data.† It is quite common to express the noise figure in decibels:

$$F_{dB} = 10\log_{10}(F).$$

Note that the noise figure of an ideal system which generates no noise itself is $F = 1$, and that portion of the noise figure of any system arising from internally generated noise is $(F - 1)$.

† The standard value for T_0 is 290 K.

Exampl 4.4.5 A given amplifier has a 4-dB noise figure, a noise bandwidth of 500 kHz, and an input resistance of 50 Ω. Calculate the rms signal input which yields an output signal-to-noise ratio of unity when the amplifier is connected to a 50-Ω input at 290 K.

Solution. The available input power is

$$P_n = kT_0B = 2.00 \times 10^{-15} \text{ watt},$$

so that

$$\overline{n_i^2(t)} = P_nR = 1.00 \times 10^{-13} \text{ volt}^2,$$
$$F = 4 \text{ dB} = 2.51.$$

Using Eq. (4.62), we have

$$(S/N)_i = F(S/N)_o = F.$$

The required input signal is

$$\overline{s_i^2(t)} = (2.51)(1.00 \times 10^{-13}) \text{volt}^2$$
$$\sqrt{\overline{s_i^2(t)}} = 0.501 \ \mu\text{V}.$$

Example 4.4.6 A resistive attenuator (e.g., a coaxial cable or waveguide) at a temperature T_0 has matched input and output resistances and an attenuation (in power) of α, where $\alpha > 1$. Determine the equivalent noise temperature and noise figure of the attenuator when the input source and the attenuator are at temperature T_0.

Solution. Using Eq. (4.65) and noting that $G_p = 1/\alpha$,

$$N_o = kT_0B(1/\alpha) + kT_eB(1/\alpha).$$

Looking back into the output terminals, the attenuator appears entirely resistive and at a temperature T_0 so that

$$N_o = kT_0B.$$

Equating these two expressions, we have

$$T_e = (\alpha - 1)T_0.$$

Use of Eq. (4.66) then yields

$$F = \alpha.$$

A similar procedure can be used if the attenuator is at some other temperature.

Example 4.4.7 A multistage amplifier has stage power gains $G_1, G_2, G_3, \ldots,$ and stage noise figures $F_1, F_2, F_3, \ldots,$ respectively. Show that the overall noise figure is

$$F = F_1 + [(F_2 - 1)/G_1] + [(F_3 - 1)/G_1G_2] + \cdots$$

and hence that the first stage is the most significant in the determination of the overall noise figure if $G_1 \gg 1$.

Solution. The result follows easily when one considers that the noise introduced by each stage is amplified only by the gains of that stage and succeeding stages. Assume a 3-stage amplifier with equivalent noise temperatures T_{e_1}, T_{e_2}, T_{e_3}:

$$
\begin{aligned}
S_o &= S_i G_1 G_2 G_3, \\
N_i &= kT_0 B, \\
N_o &= kT_0 B G_1 G_2 G_3 + kT_{e_1} B G_1 G_2 G_3 + kT_{e_2} B G_2 G_3 + kT_{e_3} B G_3 \\
&= N_i G_1 G_2 G_3 + (F_1 - 1) N_i G_1 G_2 G_3 + (F_2 - 1) N_i G_2 G_3 + (F_3 - 1) N_i G_3 \\
&= F_1 N_i G_1 G_2 G_3 + (F_2 - 1) N_i G_2 G_3 + (F_3 - 1) N_i G_3, \\
F &= \frac{S_i}{N_i} \Big/ \frac{S_o}{N_o} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}.
\end{aligned}
$$

Extensions of this result are straightforward.

This result demonstrates the advantages of using a first stage of amplification with not only a low noise figure (F_1) but also high gain (G_1). From Example 4.4.6 we see that the performance of a lossy transmission line fails on both counts. Therefore some amplification with low-noise stages is often used near or at the antenna in low-noise receiving systems before the signal is transferred (via a transmission line) to the main receiver.

Drill Problem 4.4.4 A receiver for geostationary satellite transmissions at 2 GHz consists of an antenna preamplifier with a noise temperature of 124 K and a gain of 20 dB. This is followed by an amplifier with a noise figure of 12 dB and a gain of 80 dB. Compute the overall noise figure and equivalent noise temperature of the receiver.

Answer. 2.0 dB; 170 K.

When an antenna is connected to the input of a receiver, it is convenient to represent it by a resistor which is matched to the receiver input and whose temperature represents the effective noise of the sky and the surrounding noise environment as seen through the antenna. This antenna temperature will in most cases differ substantially from 290 K.

If the input resistor, now representing an antenna, is at some arbitrary temperature T_a, we can modify Eq. (4.66) to give

$$
\begin{aligned}
N_o &= kT_a B G_p + kT_e B G_p, \\
N_o &= kB(T_a + T_e) G_p. \qquad (4.67)
\end{aligned}
$$

The equivalent noise temperature of an antenna is therefore easy to interpret and can be compared directly with the receiver noise temperature. Note that when T_a

and T_o contribute equally to the output noise, the largest possible improvement by going to a perfect receiver amounts to only a factor of two in signal-to-noise improvement. Therefore efforts to obtain a low-equivalent noise temperature in a receiver really pay large dividends only if the antenna noise temperature is low.

Average antenna noise temperatures are mainly a function of frequency and the pointing of the antenna. A graph illustrating some of the main sources of antenna noise temperature is shown in Fig. 4.13. Although the concept of noise figure is useful for the testing and comparisons of receivers, the concept of equivalent noise temperature is more useful in computations of actual system performance.

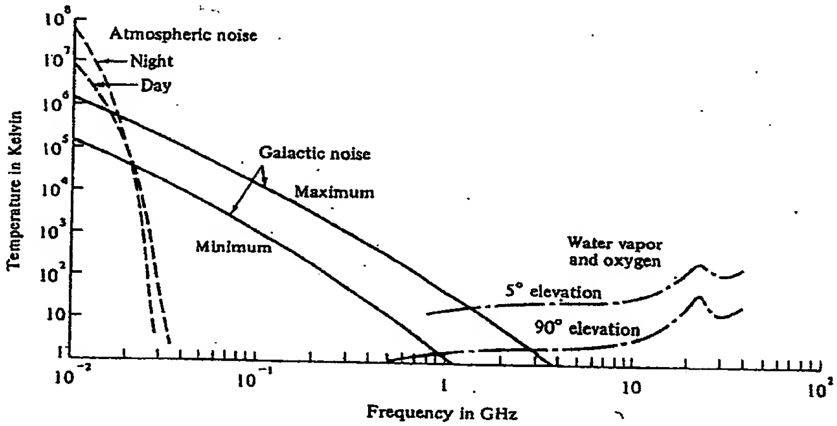

Fig. 4.13 Some average sky noise temperatures.

The principal source of antenna noise below 30 MHz is atmospheric noise which results mainly from lightning discharges. Propagation effects which make long-distance communication possible at these lower frequencies also provide good propagation for electrical storm activities occurring throughout the world. Galactic or cosmic noise is a major contributor above 30 MHz and up to the GHz range. This noise arises from radiation from outer space; for narrow beamwidths, the intensity of galactic noise is a function of antenna pointing direction. Our sun is also an active source of radiation but its effects are more localized in angular direction.

Water vapor and oxygen act as attenuators of rf energy, particularly around 23 GHz. These attenuation effects not only decrease signal strength but also act as thermal noise sources (see Example 4.4.6). The frequency range between about 2 to 8 GHz, bounded by the effects of galactic noise and noise due to oxygen and water vapor, is referred to as the "low-noise window." This is a preferred range for low-noise receivers for space telemetry and radio telescopes.